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Interactive comment on "Exploitation of the far-offshore wind energy resource by fleets of energy ships. Part A. Energy ship design and performance" *by* Aurélien Babarit et al.

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Dear Referee,

Thank you very much for reviewing our manuscript. We greatly appreciate your comments and suggestions. We have revised the manuscript accordingly. Please find below our point-by-point responses to your suggestions and concerns. We hope that you will find our responses satisfactory .

Referee's general comment: The manuscript discusses the concept of an energy ship and presents a preliminary design. The ship is driven by Flettner rotors and uses water turbines to generate electricity, which is then converted into methanol. The efficiency of the conversion process is estimated using standard formulas and making some assumptions based on current commercially available components. The ship design is very basic and it is unclear how optimal it is or what other solutions might exist in the design space. However, the aim of the authors seem to be to demonstrate the feasibility of such a concept, and for this purpose it is sufficient. The next step is to consider the economics of the design, for which the authors refer to a companion paper. The paper is well written, easy to understand and concise. The subject is relevant toWind Energy Science journal. Overall, I recommend publication of this paper.

Answer: Thank you for recommending the publication. We acknowledge that the ship design is basic and that one may wonder whether there may be other more optimal design solutions in the design space. Actually, the suggested design is an intermediate result in an on-going optimization process. We hope that we will be able to publish soon the particulars of the optimized design. Nevertheless, we think that the design described in the paper is worth publishing as we believe it is sufficient to show the feasibility of the concept, and thus that it can attract attention and enable the development of far-offshore wind energy and energy ships' research.

Referee's comment 1: The review of different approaches to offshore wind energy conversion is interesting and valuable.

Answer: No answer needed.

Referee's comment 2: The consideration of safety aspects in the choice of technology (here: motivation forbasing the design on Flettner rotors) is commendable.

Answer: No answer needed.

Referee's comment 3 : line 82: "A ... difference ... is that we propose that the energy ships are deployed in fleets" - This is mentioned in the introduction, but the idea is not picked up later. In particular, the question remains why a fleet of mid-sized ships is better than a single very large ship? Please discuss. See also my next comment.

Answer: The fleet concept is to energy ships what the farm concept is to wind turbines. It is further developed in the companion paper of this paper, which considers a 100 MW+ fleet. The fleet concept is particularly important in order to pool and optimize the use of the tankers which would supply CO2 to the energy ships and collect the produced methanol. Even if larger ships are possible, practical issues would limit the maximum dimensions anyway (i.e. shipbuilding infrastructure). Thus, even if 10 MW energy ships were possible, it would take ten ships to achieve 100 MW capacity.

Referee's comment 4 : Eq. 15: This is an interesting result that the efficiency increases for increasing turbine area. This is different from traditional wind turbines where the efficiency (under the same, implicitly made assumptions on the flow) will be constant, and it leads to a different optimum. In particular, it seems that the size of the turbine will not be as limited by the structural cost (as in wind turbines)? The manuscript should explore and discuss these scaling relationships a bit and what can be learned from them.

Answer: Thanks, this is indeed a key difference of energy ships in comparison to wind turbines. In order to address your comment, we've added a figure (Fig. 6 in the revised manuscript) which shows the absorbed power and efficiency as function of the turbine diameter. The following text has also been added in section 2.2:

"Fig. 6 shows an example of the absorbed power and efficiency η_2 as function of the water turbine diameter. One can see that, as expected, the efficiency increases with increasing turbine diameter. However, it appears that the rate of increase in efficiency diminishes with increasing turbine diameter, which is worth noting as turbine cost will also increases with increasing diameter. Therefore, despite theory indicates that as large as possible water turbine should be used, turbines of practical dimensions may be used with little efficiency loss."

Referee's comment 5 : line 200: "The electricity generated ... as function of the true wind speed and winddirection" - The equation given below this is in terms of wind speed and induction factor.How does the wind direction come into play here?

Answer: You may have confused U which is the ship velocity and W which is the true wind speed. The ship velocity does depend on the true wind speed and true wind direction, see Eqs. 2 and 8.

Referee's comment 6 : Table 1: Is there no rated ship speed? (maybe since there is no hydrodynamic design of the ship?)

Answer: In the maritime industry, the concept of rated ship speed applies to commercial ships. It is used to select propulsion power and optimize revenues. Such concept does not apply to sailing ships. Nevertheless, in the special case of energy ships, one may introduce a rated ship speed concept. Indeed, as can be seen in Figure 13, the ship velocity of the proposed design is 20 knots when it operates at full capacity. Nevertheless, we are not sure that it is worth introducing this concept for energy ships.

Referee's comment 7 : Section 3: There seems to be a gap here regarding the specification of the proposed energy ship. The previous section discusses some of the constraints and choices made and has presented some important formulas that need to be considered for designing the ship. This section suddenly presents a design, but most of the additional choices made (e.g. regarding the size of the ship and its rated power) are not motivated. Please provide some more motivation, and show how the theory presented before is used in designing the ship (if it is?)

Answer: Yes, of course, the theory which is presented in the paper has been used to develop the proposed energy ship. That's what we mean by “Using the models presented in the previous section, a design of an energy ship has been developed.”, line 264. Nevertheless, we acknowledge that further clarification is needed. To that end, we changed the title of section 3 from “3 Specifications of the proposed energy ship design” to “3 Development and specifications of the proposed energy ship design”, and we extended the first paragraph of section 4 and moved it to section 3:

“The model presented in the previous section allows the power production of a FARWINDER to be calculated as function of the wind conditions (true wind angle β, true wind speed W). As explained in that section, the induction factor a can be optimized in order to maximize energy production. Moreover, energy production depends on the thrust force of the chosen wind propulsion subsystem (Flettner rotors, see section 3.1), which itself depends on their rotational velocity. Therefore, a numerical program was developed to determine the optimal induction factor and rotational velocity as function of the FARWINDER design and the wind conditions. A brute-force search was used for the optimization. The constraints on the maximum rotational velocity of the Flettner rotors, maximum thrust on the rotors as well as maximum power of the generator of the water turbine are taken into account through penalization in the optimization loop. Using this model, we have developed, investigated and optimized a number of energy ship designs over the last two years. The details of this process are not reported here for sake of conciseness. Instead, we focus on the most promising design that has been achieved. It consists of an 80 m long catamaran with four 30 m tall Flettner rotors, and two water turbines with rated power 900 kW each, see Fig. 6. The complete specifications of this design are given in Tab. 1. The reasons for the design choices are explained in the following sections. ”

Accordingly, the beginning of section 4 has been changed to:

“The velocity and the generated power of the proposed FARWINDER are shown in Fig. 13. Five values for true wind speed were considered: 7, 10, 13, 16 and 19 m/s (corresponding to wind forces on the Beaufort scale of 4, 5, 6, 7 and 8, respectively). Note that for each datapoint, the water turbine’s induction factor and the rotors’ spin ratio were optimized in order to maximize power production while satisfying the constraints (maximum rotation velocity and thrust force for the rotors, maximum power generation for the water turbine).”

Referee’s comment 8 : Did I miss this, or what Flettner spin ratio has been chosen for the ship - and why? Can this parameter be optimized mathematically? (For example, Eq. 9 and thereby theship speed is influenced by the spin ratio) Is it advantageous if the spin is larger? What is the drag to lift ratio dependence on spin (include a figure, if possible)? Is more known about the efficiency of Flettner rotors (i.e., what are the mechanical losses relative onspin ratio?)

Answer: Yes, the spin ratio is also part of the power production optimization. We believe that your comment has been adressed in our answer to your comment 7.

Referee's comment 9 : line 315: "an important question is whether this structural mass is sufficient to ensure that the ship can withstand harsh ocean conditions" - Indeed. It is a bit disappointingto see not even a very basic consideration of hydrodynamic design and its constraints here. For example, hydrodynamic stability seems a critical issue, with the tall Flettner rotors and the low draft of the ship. I hope the authors will pick up this issue, if not now, then in the future.

Answer: Although not reported in the paper, stability has been considered in the design process. It is actually one of the reason for selecting a multihull design. For the presented design, given the breadth of the ship, stability would not be an issue at all despite the tall Flettner rotors (maximum heeling angle in the order of a few degrees). Anyway, yes, we are currently working on the hydrodynamic design of the hull including structural aspects. We hope to be able to publish results in the close future.

Referee's comment 10 : line 369: "a numerical program was developed" - Will this be available to reader as Open Source or public domain software, e.g. on Github? Please include a "Code availability" section in the manuscript

Answer: This program will not be available as open source or public domain. It may be purchased from Ecole Centrale de Nantes. However, note that this program is just an implementation of the theory presented in the paper, thus one may develop one's own code. Nevertheless, we've added the following "data and code availability" section:

"Data and code availability The data generated during the current study are available from the corresponding author on request. Licences of the numerical program which was used to develop the proposed energy ship and assess its energy performance may be purchased from Ecole Centrale de Nantes."

Minor comments :

1- line 50: "100 to 150,000 deadweight tonnage" - I assume this to be 100,000 to 150,000 dwt? Please clarify.

Answer: In (Kim & Park, 2010), they considered a small ship of 100 dwt and a large ship of 150,000 dwt. The ships are propelled by kites sailing at 1,481 m altitude. According to their model, the small ship can produced 5.69 MW and the large ship can produce 805.2 MW. To avoid confusion, we removed the mention "100 to 150,000 deadweight tonnage".

2- line 78: This should probably read "the lift depends on only one control variable"?

Answer: Yes, corrected, thank you.

3- Line 85: "CO2" would more commonly be written with subscript, I think?

Answer: Yes, corrected, thank you.

4- line 141: "the drag force generated by the turbine" - It seems strange (and not entirely correct) to call it this. Isn't this simply the thrust force generated by the turbine?

Answer: Yes, it is the thrust generated by the turbine. However, it can be discussed whether it should be called thrust or drag for an energy ship. Indeed, from the ship's perspective, this force opposes to the forward motion, whereas a thrust force would normally be oriented forward (as that would be provided by a propeller). Nevertheless, we decided to follow your suggestion: "RT is the drag force generated by the turbine" -> "RT is the thrust force generated by the turbine" "In addition to the drag force generated by the turbine" > "In addition to the force generated by the turbine" "the thrust force is equal to the turbine resistance plus the water resistance" -> "the thrust force is equal to the turbine force plus the water resistance”. “proportional to the drag force generated by the turbine” -> “proportional to the turbine force”

5- Eq. 17: The font is probably wrong, it should be roman for chemical formulas

Answer: The formatting will be managed by the editor.

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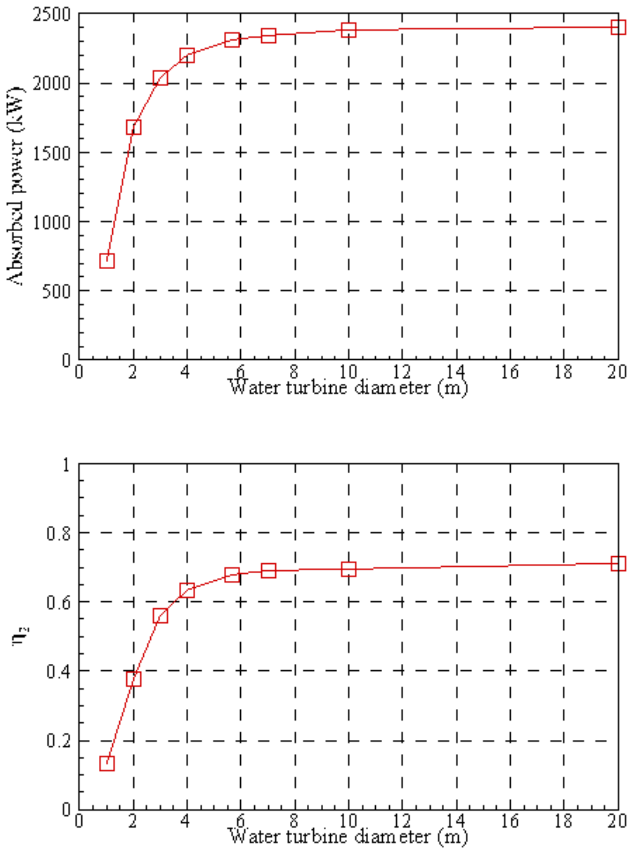

Fig. 1. New Figure 6: Absorbed power (top) and propulsion power to water turbine mechanical power (bottom) as function of the water turbine diamer. The true wind speed is 10 m/s and the true wind angle is 90°

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Discussion paper